# A Method for Determining Autoignition Temperatures Resulting from Varying Rapid Rise Rates

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**[Abstract] Pyrotechnic and explosive devices are widely used in the aerospace industry to provide reliable, lightweight initiation components in ignition systems, cartridge actuated devices, escape and ejection systems, and many other applications. There are two major mechanisms for initiation of the pyrotechnic powders: heat and shock. Of powders initiated by heat, we have little information on the temperature required for ignition in the normal functioning time (milliseconds) of the device. The known autoignition temperatures obtained from standard tests provide data from days down to minutes with temperatures increasing as heating time decreases. In order to better understand this relationship, and to make computer models, improved data are needed.**

## I. Introduction

THIS paper provides a method of determining the autoignition temperature (AIT) of powders with very short times to ignition, varying from seconds down to the microsecond range. More importantly, it presents a method of applying heat to a small area and measuring the actual temperature achieved. The data presented are from the testing of titanium hydride potassium perchlorate ($TiH_2KClO_4$), commonly called THPP. This material is often only one element in a pyrotechnic train in which a separate initiation device provides heat to ignite the THPP.

Pyrotechnic and explosive devices are widely used in the aerospace industry to provide reliable, lightweight initiation components in ignition systems, cartridge actuated devices, escape and ejection systems, and many other applications. Very little information exists concerning the temperature required to ignite pyrotechnic powders in the normal functioning time (milliseconds) of the device. The transmission of heat from the initiator to a secondary or booster charge is critical for proper operation of the device.

The AITs of these powders are known from standard tests at various conditions (e.g., over much longer heating times than those encountered in a nominal pyrotechnic device). These standard AIT tests vary greatly, from a fuel fire to oven temperatures ramped up at different rates. The known AITs obtained from standard tests at various pyrotechnic or explosive conditions may be useful for a specific application; but one common result of these test data is that the AIT increases as the heating time decreases.

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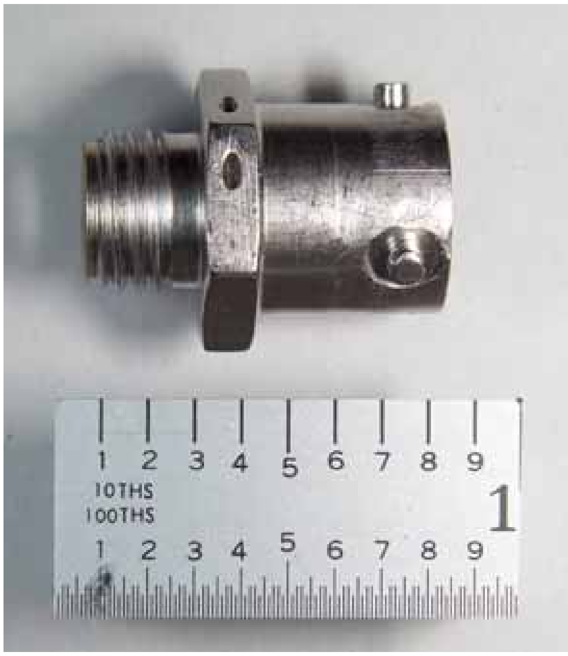


**Figure 1. Side View of the THPP Ignition Temperature Test Article**

For these tests, an initiator body, similar to that used for common pyrotechnic initiations, was loaded with a standard pyrovalve booster charge consisting of a mixture of THPP (Figure 1). The THPP mixture was compressed using a force of 5,000 psi. Embedded in the compressed THPP was a 0.002-in.-diameter 304L stainless steel bridgewire approximately 0.118 in. long. The resistance of this bridgewire is approximately 1 ohm at ambient temperature.

With the powder packed around the bridgewire, it is possible to input heat to the powder at a given rate over a short period of time. Because the bridgewire changes resistance as it is heated, it is also possible to measure the temperature of the bridgewire as it heats the powder immediately around it.

The 304L stainless wire, according to the manufacturer, has a thermal coefficient of resistivity of 850 ohms per million ohms per degrees C change in temperature.[1] The manufacturer states that this coefficient is good from 0 °C to 100 °C. The thermal coefficient of resistivity needed to be verified over a much higher temperature range (near 1,000 °C) to measure the AIT of THPP.

A sample was obtained of the same lot of wire used in the test units. A short length of the wire was welded onto two stainless steel rods. The rods and the sample wire were kept apart by ceramic sheathing (Figure 2). This allowed the entire length of bridgewire to be lowered into a calibrated furnace (Figure 3).

The furnace temperature was increased in increments of ~ 300 °C. After the bridgewire sample in its ceramic sheath had come to equilibrium at each step, the resistance was measured. Two tests were conducted ranging from room temperature 23.7 °C (74.65 °F) to 1051 °C (1923.77 °F). The data gave an average change of resistance of 865 ohms per million ohms per °C (Figure 4).

## II. Testing of THPP

The AIT of the THPP was determined by passing a constant current pulse of short duration through the bridgewire embedded in the powder. If ignition did not occur, the current passing through the bridgewire was increased in specific increments until autoignition was achieved. As current passed through the bridgewire, the resistance of the wire increased as the temperature of the wire increased.[2,3] Since the current was held constant, the voltage in the circuit increased as the resistance of the wire increased. Current and voltage were measured over time and used to calculate the resistance of the wire at the exact time that the THPP ignited. The ignition temperature can then be calculated from the following general relationship:[4, 5]

$$R_2 = R_1(1 + \alpha(T_2 - T_1))$$

Where:

$R_2$ is the resistance in ohms at temperature $T_2$ (°C)
$R_1$ is the resistance in ohms at temperature $T_1$ (°C); $T_1$ is usually ambient temperature
$\alpha$ is the thermal coefficient of resistance, ohms/million ohms/°C)

The above equation can be expressed as:

$$T_2 = 1{,}000{,}000*(R_2 - R_1)/\alpha R_1 + T_1$$

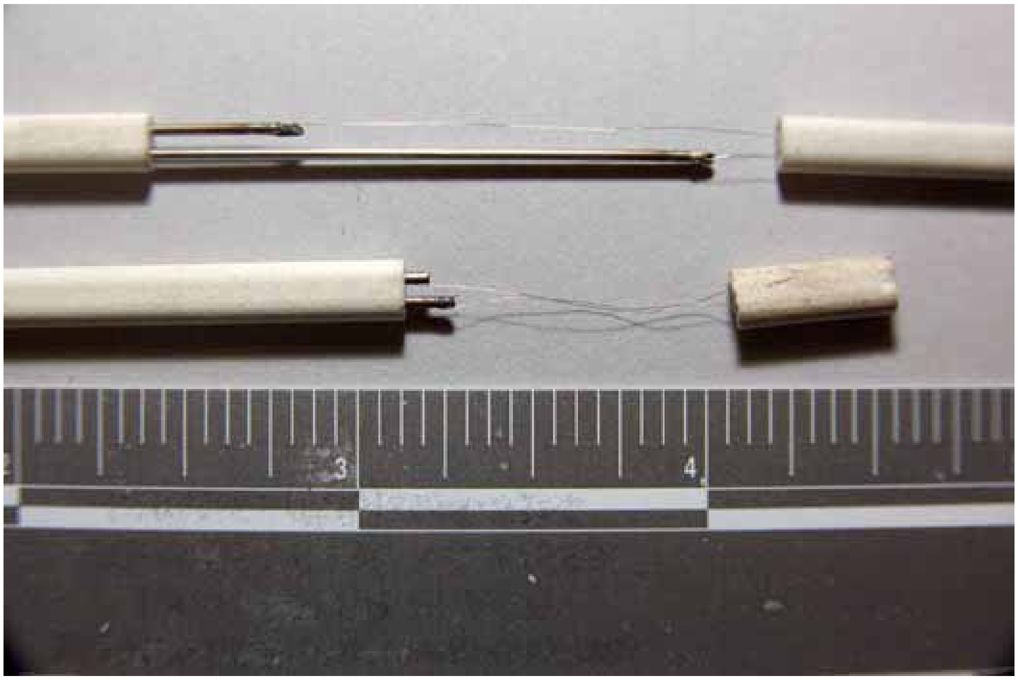


**Figure 2. Bridgewire Sample Attached to Two Steel Rods.**

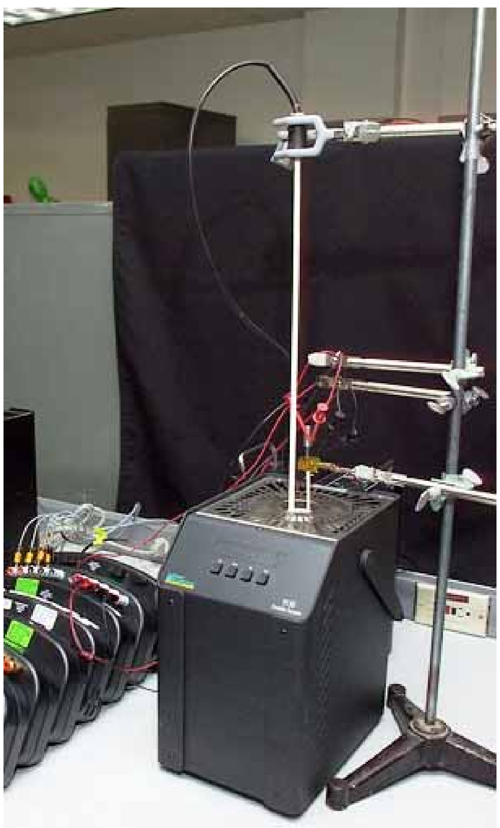

**Figure 3. Bridgewire Resistance Test Setup**

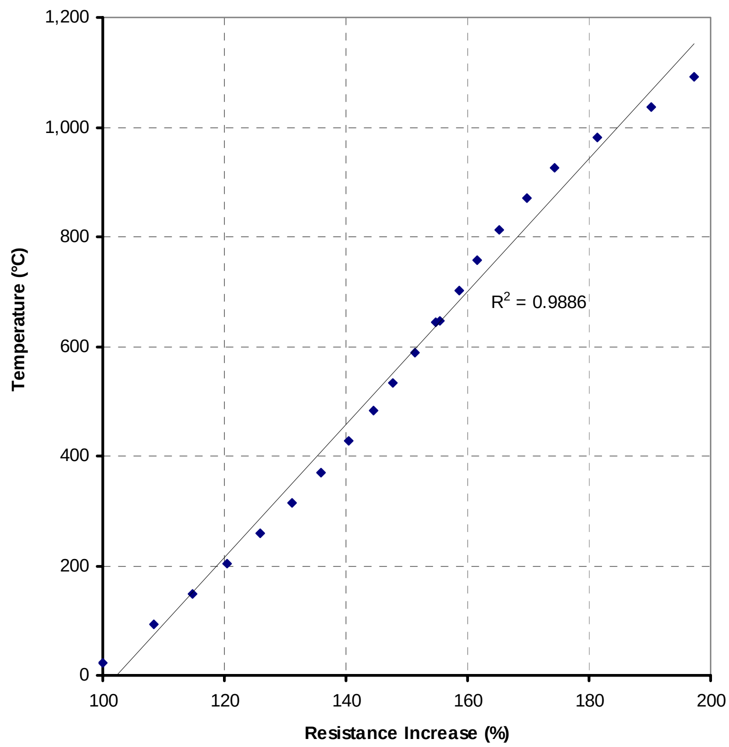


**Figure 4. Temperature vs. Cold Resistance**

The first tests were performed with a 10-millisecond (ms) pulse of constant amperage. The first pulse was set at 1.0 amperes (0.9723 amperes actual). During each pulse, the current and the voltage required to maintain constant amperage were recorded. At the end of each pulse, the last current and voltage recorded were used to calculate the resistance of the bridgewire. The last voltage recorded during each pulse was the highest in every case, so this gave the highest temperature achieved during the pulse. After a 3-min wait to allow the bridgewire to cool, the amperage was increased by 0.10 amperes, and another 10-ms pulse applied. This was continued until autoignition was achieved and the unit fired. The test was repeated with two more units. The three units fired with actual current pulses of 2.2632, 2.2739, and 2.2757 amperes respectively. The corresponding AITs were 718.5, 682, and 715.4 °C (1,325, 1,260, and 1,320 °F). The complete data and graph are contained in Figure 5.

| Summary of Bridgewire Autoignition Tests of THPP | | | | | |
|---|---|---|---|---|---|
| Test | Programmed Time of Firing Pulse (ms) | Actual Time of Firing Pulse (ms) | Amperage of Firing Pulse (amps) | Maximum Temperature Reached (°C) | Fired During or After Pulse |
| 1 | 2.0 | 1.76 | 4.97 | 1,082 | After Pulse |
| 2 | 2.0 | 1.76 | 4.47 | 860 | After Pulse |
| 3 | 10.0 | 9.60 | 2.26 | 701 | After Pulse |
| 4 | 10.0 | 9.60 | 2.28 | 705 | After Pulse |
| 5 | 10.0 | 9.60 | 2.27 | 719 | After Pulse |
| 6 | 100.0 | 49.40 | 1.47 | 627 | During Pulse |
| 7 | 100.0 | 70.40 | 1.53 | 714 | During Pulse |
| 8 | 1,000.0 | 178.00 | 1.46 | 603 | During Pulse |
| 9 | 1,000.0 | 311.00 | 1.52 | 746 | During Pulse |

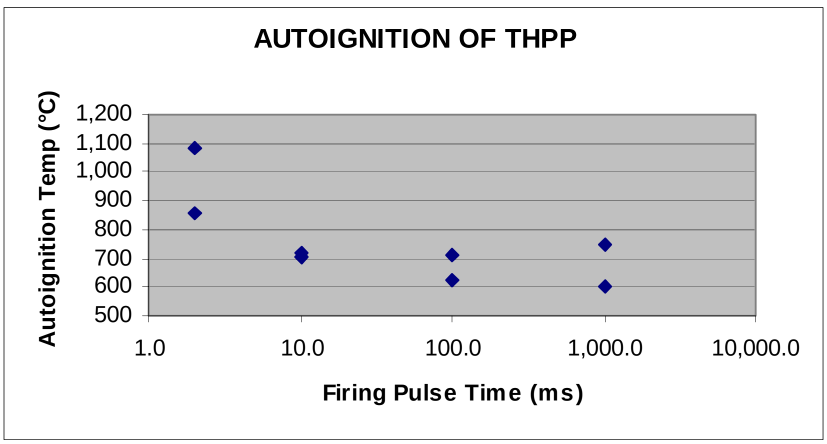


**Figure 5. Summary of Bridgewire Autoignition Tests of THPP**

Because the first three units had very consistent results, the pulse width was changed for subsequent tests. Two units were tested with a 1,000-ms pulse, two units with a 100-ms pulse, and two units with a 2-ms pulse. The starting amperage and each amperage increment were adjusted according to the pulse width for a particular test. The final results are found in Figure 6.

An interesting note from the final data was that the two units tested with a 100-ms pulse, and the two units tested with a 1,000-ms pulse, all went off *during* the pulse; and the two units tested with a 2-ms pulse, and the three units tested with a 10-ms pulse, all went off *after* the pulse was turned off. This may indicate two separate modes of firing. For the units at 2-ms and the three at 10-ms, the temperature was still rising when the pulse was turned off. On the two units at 100-ms and two units at 1,000-ms, the temperature was almost flat, indicating the heat being input through the bridgewire was being conducted away at nearly the same rate as being input. This temperature conduction is highly dependent on the configuration of the body of the initiator, and possibly the way it is mounted. In further testing, this should be considered as a separate variable.

In a parallel test effort, the AITs for both loose and packed THPP were determined using the standard method ASTM G72-01.[6] This method uses a constant and standard temperature rise of 5 °C (9 °F) per minute. The results of these tests are summarized in Table 1. The AITs averaged 261.5 °C with a high of 276.1 °C and a low of 249.4 °C. These results are very consistent and can easily be related to other materials because a standard test method was used. However, it also can be seen that the AITs determined by this method are far lower than those determined by the rapid temperature rise method.

**Table 1. Autoignition Temperature of THPP Supplied by Pac-Sci**

| Packed THPP[a] | | | | | | Loose THPP[a] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Rate of Temp Increase (°C/min) | Autoignition Temperature (°C) | Ignition Pressure (psia) | Pressure Rise on Ignition (psi) | | Date | Rate of Temp Increase (°C/min) | Autoignition Temperature (°C) | Ignition Pressure (psia) | Pressure Rise on Ignition (psi) |
| 11/02/06 | 5.4 | 252.2 | 20[b] | 0[b] | | 11/13/06 | 5.2 | 273.9 | 32 | 5 |
| 11/02/06 | 5.2 | 266.7 | 31 | 6 | | 11/13/06 | 5.6 | 271.7 | 31 | 5 |
| 11/02/06 | 5.2 | 252.8 | 31 | 6 | | 11/13/06 | 5.3 | 250.0 | 30 | 6 |
| 11/02/06 | 5.1 | 276.1 | 22 | 5 | | 11/13/06 | 5.2 | 259.4 | 28 | 6 |
| 11/06/06 | 5.6 | 260.0 | 30 | 6 | | 11/13/06 | 5.2 | 249.4 | 29 | 5 |
| | | | | | | 11/15/06 | 6.7 | 258.3 | 31 | 5 |
| | | | | | | 11/16/06 | 3.2 | 267.2 | 30 | 6 |
| | | | | | | | | | | |
| **Average** | | **261.6** | | | | | | **261.4** | | |

[a]All tests were conducted per ASTM G 72-01 in nitrogen gas at a starting pressure of 15 psia.
[b]A test chamber leak was noticed during Test 1 with the packed THPP

| | Current | Voltage | Resistance | Temp °C | Temp °F | | |
|---|---|---|---|---|---|---|---|
| Test #1 12/6/2006 | 0.9723 | 1.0196 | 1.0486 | 22.2 | 72.0 | | |
| | 0.9625 | 1.1896 | 1.2359 | 228.7 | 443.6 | Ro = | 1.05 |
| | 1.0657 | 1.3507 | 1.2674 | 263.4 | 506.1 | To (°C) = | 22.2 |
| | 1.1690 | 1.5237 | 1.3034 | 303.1 | 577.5 | Cr = | 865 |
| | 1.2781 | 1.7023 | 1.3319 | 334.5 | 634.0 | | |
| | 1.3651 | 1.8936 | 1.3872 | 395.4 | 743.7 | | |
| | 1.4630 | 2.0850 | 1.4252 | 437.3 | 819.1 | | |
| | 1.5585 | 2.2958 | 1.4731 | 490.1 | 914.2 | | |
| | 1.6670 | 2.5128 | 1.5074 | 527.9 | 982.3 | | |
| | 1.7679 | 2.7274 | 1.5427 | 566.9 | 1,052.4 | | |
| | 1.8640 | 2.9300 | 1.5719 | 599.0 | 1,110.3 | | |
| | 1.9641 | 3.1290 | 1.5931 | 622.4 | 1,152.4 | | |
| | 2.0657 | 3.3322 | 1.6131 | 644.5 | 1,192.1 | | |
| | 2.1597 | 3.5580 | 1.6475 | 682.3 | 1,260.2 | | |
| | 2.2632 | 3.8028 | 1.6803 | 718.5 | 1,325.4 | | |
| Test #2 12/6/2006 | 0.9555 | 1.0516 | 1.1006 | 22.2 | 72.0 | | |
| | 0.9659 | 1.2241 | 1.2673 | 197.3 | 387.2 | Ro = | 1.10 |
| | 1.0605 | 1.3910 | 1.3116 | 243.9 | 471.0 | To (°C) = | 22.2 |
| | 1.1600 | 1.5665 | 1.3504 | 284.7 | 544.4 | Cr = | 865 |
| | 1.2677 | 1.7560 | 1.3852 | 321.2 | 610.1 | | |
| | 1.3828 | 1.9574 | 1.4155 | 353.0 | 667.5 | | |
| | 1.4780 | 2.1542 | 1.4575 | 397.1 | 746.8 | | |
| | 1.5738 | 2.3718 | 1.5071 | 449.2 | 840.5 | | |
| | 1.6736 | 2.5931 | 1.5494 | 493.7 | 920.6 | | |
| | 1.7786 | 2.8073 | 1.5784 | 524.1 | 975.4 | | |
| | 1.8854 | 3.0304 | 1.6073 | 554.5 | 1,030.1 | | |
| | 1.9666 | 3.2422 | 1.6486 | 597.9 | 1,108.2 | | |
| | 2.0880 | 3.4546 | 1.6545 | 604.1 | 1,119.3 | | |
| | 2.1872 | 3.6792 | 1.6822 | 633.1 | 1,171.6 | | |
| | 2.2739 | 3.9310 | 1.7287 | 682.0 | 1,259.7 | | |
| Test #3 12/7/2006 | 0.9717 | 1.0498 | 1.0804 | 22.2 | 72.0 | | |
| | 0.9628 | 1.2256 | 1.2730 | 228.3 | 442.9 | Ro = | 1.08 |
| | 1.0715 | 1.3873 | 1.2947 | 251.6 | 484.8 | To (°C) = | 22.2 |
| | 1.2793 | 1.7804 | 1.3917 | 355.3 | 671.6 | Cr = | 865 |
| | 1.2784 | 1.7749 | 1.3884 | 351.8 | 665.2 | | |
| | 1.3828 | 1.9745 | 1.4279 | 394.1 | 741.3 | | |
| | 1.4771 | 2.1500 | 1.4556 | 423.7 | 794.6 | | |
| | 1.5845 | 2.3734 | 1.4979 | 469.0 | 876.1 | | |
| | 1.6608 | 2.5925 | 1.5610 | 536.5 | 997.7 | | |
| | 1.7780 | 2.8134 | 1.5823 | 559.3 | 1,038.8 | | |
| | 1.8857 | 3.0316 | 1.6077 | 586.4 | 1,087.6 | | |
| | 1.9745 | 3.2455 | 1.6437 | 625.0 | 1,157.0 | | |
| | 2.0813 | 3.4500 | 1.6576 | 639.9 | 1,183.8 | | |
| | 2.1811 | 3.6783 | 1.6864 | 670.7 | 1,239.3 | | |
| c | 2.2757 | 3.9328 | 1.7282 | 715.4 | 1,319.7 | | |

Initial temperature for all runs is estimated at 72 °F or 22.2 °C
Values in yellow highlight are the initial readings from each test series.
This initial calculated resistance is then used in the rest of the calculations for that series.

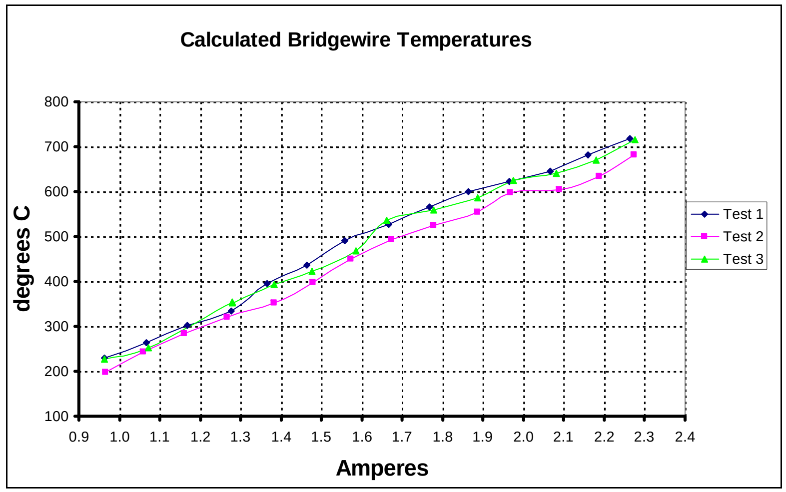


**Figure 6. Highest Temperature Achieved with Each 10-ms Pulse**

## III. Conclusion

This method can provide a high rate of controlled heat input to a pyrotechnic powder. This rate of heat input more closely simulates what the ordnance material will experience in actual use. The AIT under these conditions, which can be calculated quite reliably, is much higher than AITs determined by more traditional methods. The valuable information on pyrotechnic and explosive interfaces gained by using this method could help in determining margins for actuation and in more accurate modeling of ordnance initiation mechanisms.

## IV. References


[1] Technical Data Sheet. *Stainless Steel 304: Material Number 100192.* California Fine Wire Company, Grover Beach, California. © 2002.

[2] MIL-STD-1512(1) NOT 2 (Canceled 1997) (DISA), "Electroexplosive Subsystems, Electrically Initiated, Design Requirements and Test Methods," *Method 206: Thermal Time Constant*, Department of Defense, Washington, D.C., March 21, 1972.

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[4] "Thermal Response Testing of Electroexplosive Devices," Proceedings of the *9th Symposium on Explosives and Pyrotechnics*, Hi-Shear Corporation, Philadelphia, Pennsylvania, September 15, 1976.

[5] Baumeister, Theodore (editor). *Standard Handbook for Mechanical Engineers*, 7$^{th}$ edition, McGraw-Hill Book Company, pg. 15-6 – 15-8, 1967.

[6] ASTM G72-01. *Standard Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment*. American Society for Testing and Materials, West Conshohocken, Pennsylvania (2001, or most current revision).

# A Method for Determining Autoignition Temperatures Resulting from Varying Rapid Rise Rates

Michael Hagopian, Kenneth McCardle, Stephen McDougle,
Regor Saulsberry, and William Sipes

# Introduction

- Pyrotechnic devices provide reliable, lightweight solutions in many aerospace applications.
- Standard methods of determining the temperature required to ignite the pyrotechnic powders use heating time periods on the order of minutes or days.
- These methods indicate that the autoignition temperature increases when the rate of heating the powder increases.
- Measuring the autoignition temperature in the normal functioning time of the device, milliseconds (ms), will more closely simulate what the powder will experience in actual use.

# Standard Test Method ASTM G72-01

- Autoignition temperatures of both loose and packed titanium hydride/potassium perchlorate (THPP) were determined using standard method ASTM G72-01.
- The standard temperature rise of 5 °C/min (nominal) was used.
- Five tests were performed with the loose THPP and five were performed with the packed THPP.
- Two additional tests were performed by changing the heating rate to 3.2 °C and 6.7 °C.
- The autoignition temperatures averaged 261.5 °C with a low of 249.4 °C and a high of 276.1 °C.

# ASTM G72-01 Results

## Autoignition Temperature of THPP Supplied By Pac-Sci

### Packed THPP[1]

| Date | Rate Of Temp Increase (°C/min) | Autoignition Temperature (°C) | Ignition Pressure (psia) | Press Rise On Ignition (psi) |
|---|---|---|---|---|
| 11/02/06 | 5.4 | 252.2 | 20[2] | 0[2] |
| 11/02/06 | 5.2 | 266.7 | 31 | 6 |
| 11/02/06 | 5.2 | 252.8 | 31 | 6 |
| 11/02/06 | 5.1 | 276.1 | 22 | 5 |
| 11/06/06 | 5.6 | 260.0 | 30 | 6 |
| **Average** | | **261.6** | | |

### Loose THPP[1]

| Date | Rate Of Temp Increase (°C/min) | Autoignition Temperature (°C) | Ignition Pressure (psia) | Press Rise On Ignition (psi) |
|---|---|---|---|---|
| 11/13/06 | 5.2 | 273.9 | 32 | 5 |
| 11/13/06 | 5.6 | 271.7 | 31 | 5 |
| 11/13/06 | 5.3 | 250.0 | 30 | 6 |
| 11/13/06 | 5.2 | 259.4 | 28 | 6 |
| 11/13/06 | 5.2 | 249.4 | 29 | 5 |
| 11/15/06 | 6.7 | 258.3 | 31 | 5 |
| 11/16/06 | 3.2 | 267.2 | 30 | 6 |
| | | **261.4** | | |

[1]All tests were conducted per ASTM G 72-01 in nitrogen gas at a starting pressure of 15 PSIA

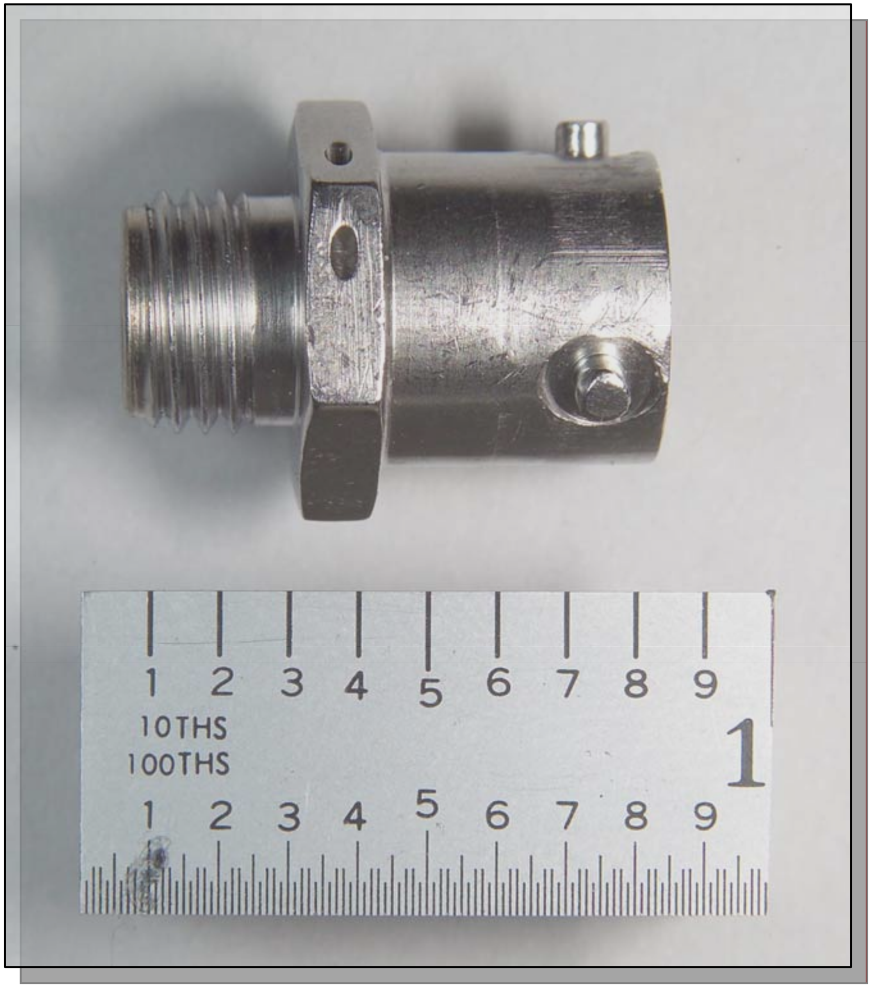
[2]A test chamber leak was noticed during Test 1 with the packed THPP

# Approach

- An initiator body, similar to those used in many pyrotechnic aerospace applications, was loaded with a standard booster charge consisting of a mixture of titanium hydride and potassium perchlorate (THPP).
- Embedded in the powder was a 0.002-in. diameter 304L stainless steel wire. In this configuration, the wire is commonly called a bridgewire.
- A programmable power supply was used to vary the heat applied to the THPP by changing the amperage of the current applied to the bridgewire.

# Approach (continued)

## Test Article



# Approach (continued)

- Amperage was held constant during each pulse.
- As the bridgewire heats, its electrical resistance increases. The power supply maintains the constant current at the higher resistance by increasing the voltage.
- The autoignition temperature is calculated from the initial resistance and temperature at ambient conditions, and the coefficient of thermal resistivity of the bridgewire.

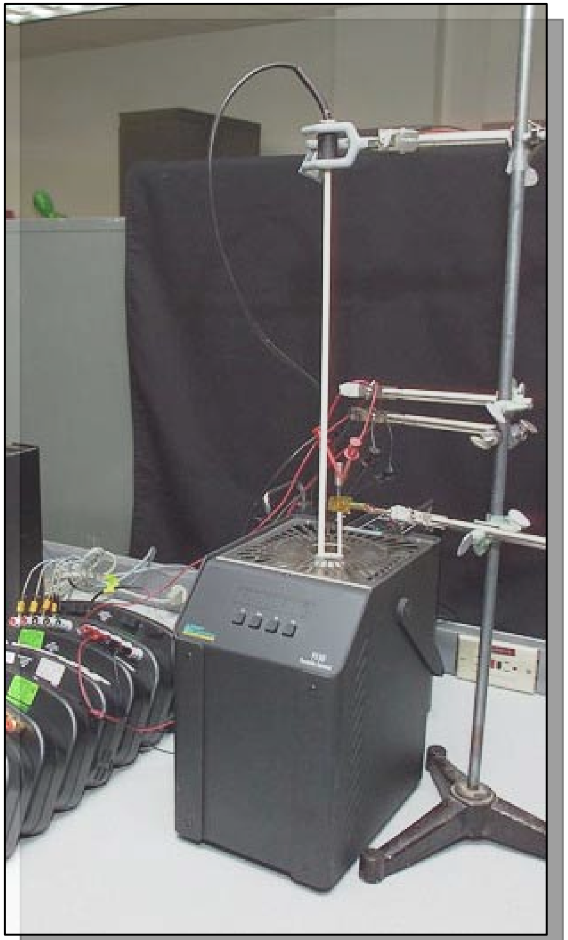
# Approach (continued)

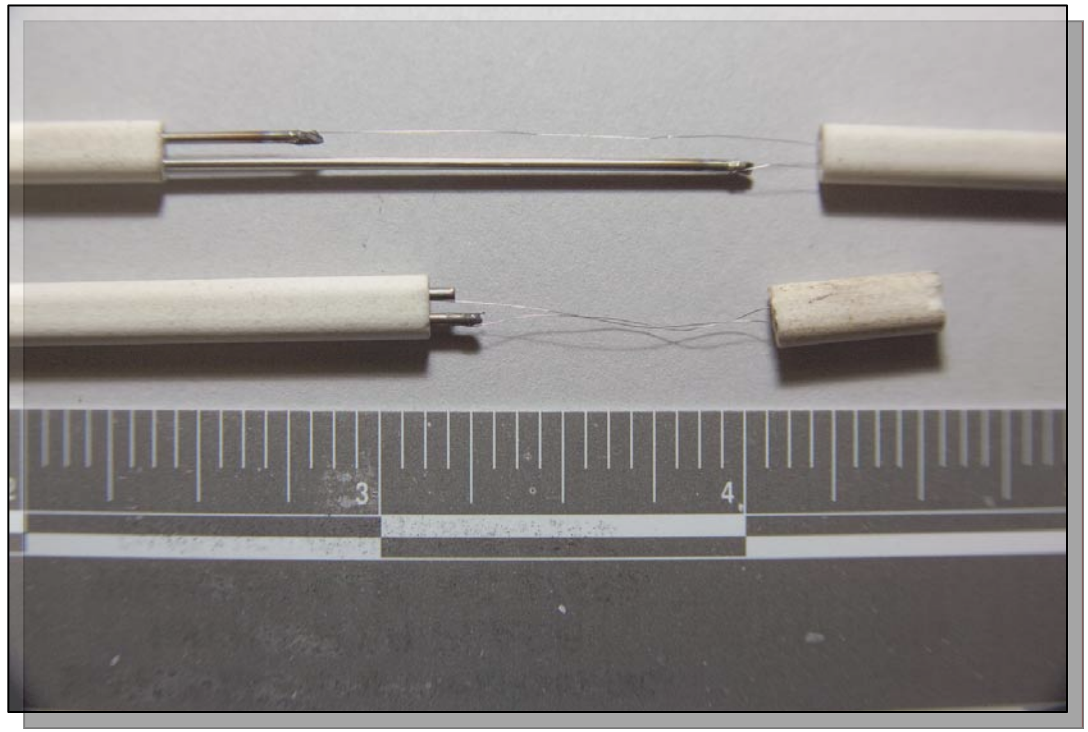
- Because the coefficient of thermal resistivity of the bridgewire material is a key parameter in the temperature calculation, it was checked in a separate test.

# Coefficient of Thermal Resistivity

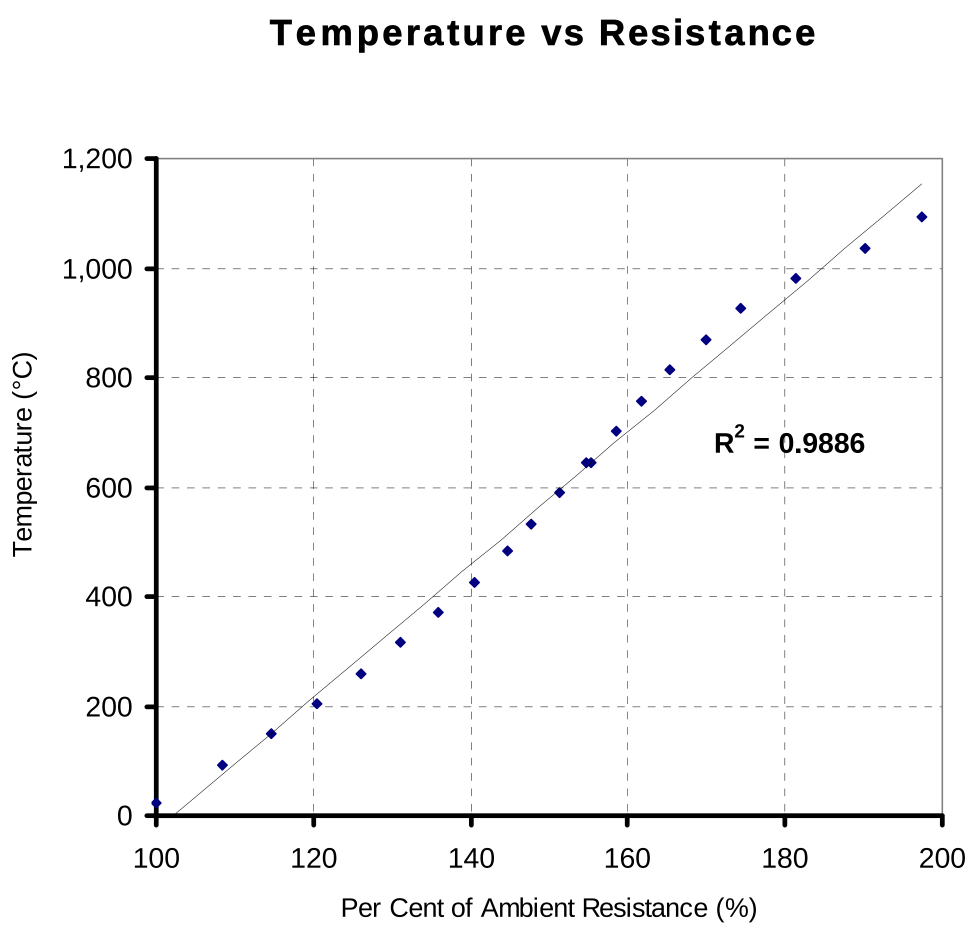
- A sample of the bridgewire was obtained from the manufacturer.
- The sample was heated in a calibrated furnace to temperatures ranging from 23.6 °C (74.48 °F) to 1050.98 °C (1923.77 °F). When the temperature had stabilized, the bridgewire resistance was measured to four decimal places.
- The coefficient was determined to be 865 ohms per million ohms per °C.

# Coefficient of Thermal Resistivity (continued)





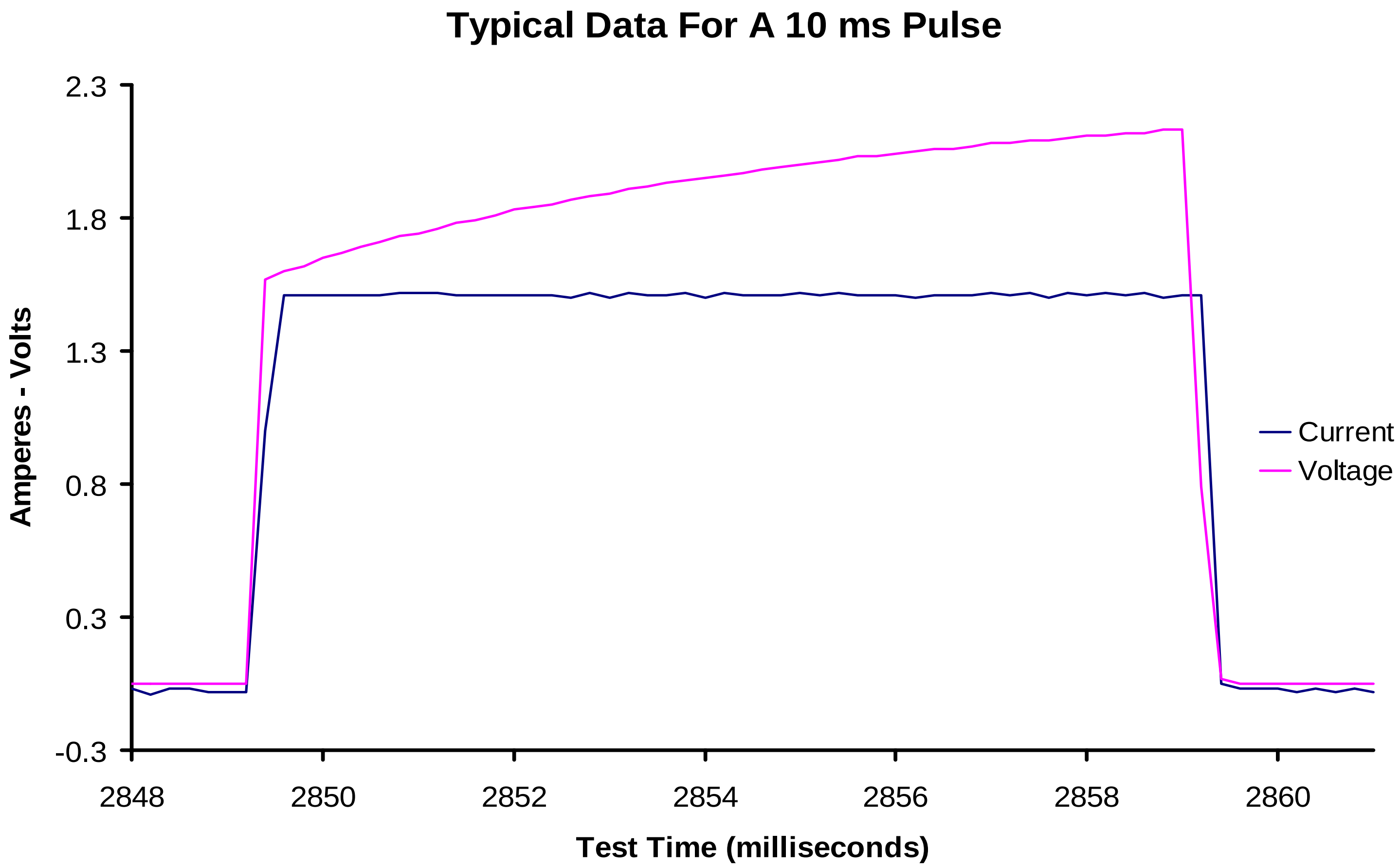
# Coefficient of Thermal Resistivity (continued)



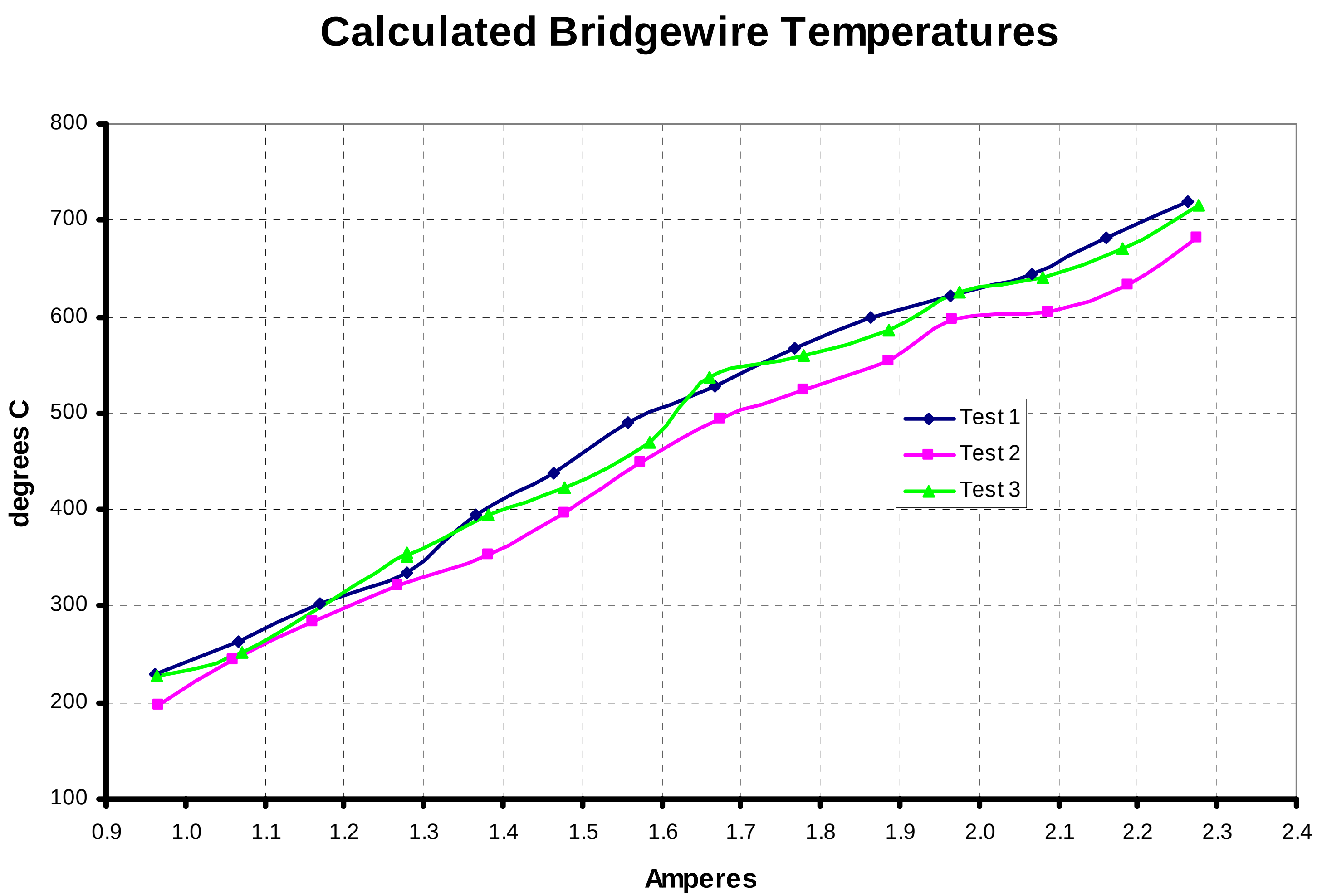
# 10 ms Pulse Tests

- The first pulse was set at 1.0 amperes.  After a 3-min wait to allow the bridgewire to cool, the amperage was increased by 0.10 amperes and another 10-ms pulse was applied.
- The amperage was raised in 0.10 ampere steps until autoignition was achieved.

# 10 ms Pulse – Typical Data



# Bridgewire Temperatures at End of 10-ms Pulses



# Autoignition Tests Performed

- The last recorded current and voltage just before the autoignition were used to calculate the ignition temperature.
- Pulse width was changed for subsequent tests; two units were tested with a 1,000-ms pulse, two units with a 100-ms pulse, and two units with a 2-ms pulse.

# Autoignition Temperature Results

| Summary of Bridgewire Autoignition Tests of THPP | | | | | |
|---|---|---|---|---|---|
| Test | Programmed Time of Firing Pulse (ms) | Actual Time of Firing Pulse (ms) | Amperage of Firing Pulse (amps) | Maximum Temperature Reached (°C) | Fired During or After Pulse |
| 1 | 2.0 | 1.76 | 4.97 | 1,082 | After Pulse |
| 2 | 2.0 | 1.76 | 4.47 | 860 | After Pulse |
| 3 | 10.0 | 9.60 | 2.26 | 701 | After Pulse |
| 4 | 10.0 | 9.60 | 2.28 | 705 | After Pulse |
| 5 | 10.0 | 9.60 | 2.27 | 719 | After Pulse |
| 6 | 100.0 | 49.40 | 1.47 | 627 | During Pulse |
| 7 | 100.0 | 70.40 | 1.53 | 714 | During Pulse |
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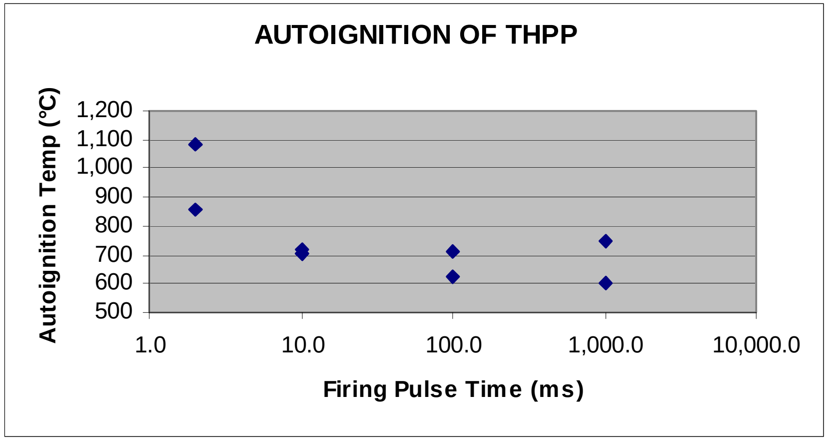

# Conclusion

- Autoignition temperatures determined by the bridgewire resistance method are far higher than those determined by the standard methods.
- The bridgewire resistance method more closely simulates what the ordnance materials will experience in service.
- The valuable information gained by using this method could help in determining margins for actuation and in more accurate modeling of ordnance initiation mechanisms.

# A Method for Determining Autoignition Temperatures Resulting from Varying Rapid Rise Rates

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# Introduction

- Pyrotechnic devices provide reliable, lightweight solutions in many aerospace applications.
- Standard methods of determining the temperature required to ignite the pyrotechnic powders use heating time periods on the order of minutes or days.
- These methods indicate that the autoignition temperature increases when the rate of heating the powder increases.
- Measuring the autoignition temperature in the normal functioning time of the device, milliseconds (ms), will more closely simulate what the powder will experience in actual use.

# Standard Test Method ASTM G72-01

- Autoignition temperatures of both loose and packed titanium hydride/potassium perchlorate (THPP) were determined using standard method ASTM G72-01.
- The standard temperature rise of 5 °C/min (nominal) was used.
- Five tests were performed with the loose THPP and five were performed with the packed THPP.
- Two additional tests were performed by changing the heating rate to 3.2 °C and 6.7 °C.
- The autoignition temperatures averaged 261.5 °C with a low of 249.4 °C and a high of 276.1 °C.

# ASTM G72-01 Results

## Autoignition Temperature of THPP Supplied By Pac-Sci

### Packed THPP[1]

| Date | Rate Of Temp Increase (°C/min) | Autoignition Temperature (°C) | Ignition Pressure (psia) | Press Rise On Ignition (psi) |
|---|---|---|---|---|
| 11/02/06 | 5.4 | 252.2 | 20[2] | 0[2] |
| 11/02/06 | 5.2 | 266.7 | 31 | 6 |
| 11/02/06 | 5.2 | 252.8 | 31 | 6 |
| 11/02/06 | 5.1 | 276.1 | 22 | 5 |
| 11/06/06 | 5.6 | 260.0 | 30 | 6 |
| | **Average** | **261.6** | | |

### Loose THPP[1]

| Date | Rate Of Temp Increase (°C/min) | Autoignition Temperature (°C) | Ignition Pressure (psia) | Press Rise On Ignition (psi) |
|---|---|---|---|---|
| 11/13/06 | 5.2 | 273.9 | 32 | 5 |
| 11/13/06 | 5.6 | 271.7 | 31 | 5 |
| 11/13/06 | 5.3 | 250.0 | 30 | 6 |
| 11/13/06 | 5.2 | 259.4 | 28 | 6 |
| 11/13/06 | 5.2 | 249.4 | 29 | 5 |
| 11/15/06 | 6.7 | 258.3 | 31 | 5 |
| 11/16/06 | 3.2 | 267.2 | 30 | 6 |
| | | **261.4** | | |

[1] All tests were conducted per ASTM G 72-01 in nitrogen gas at a starting pressure of 15 PSIA

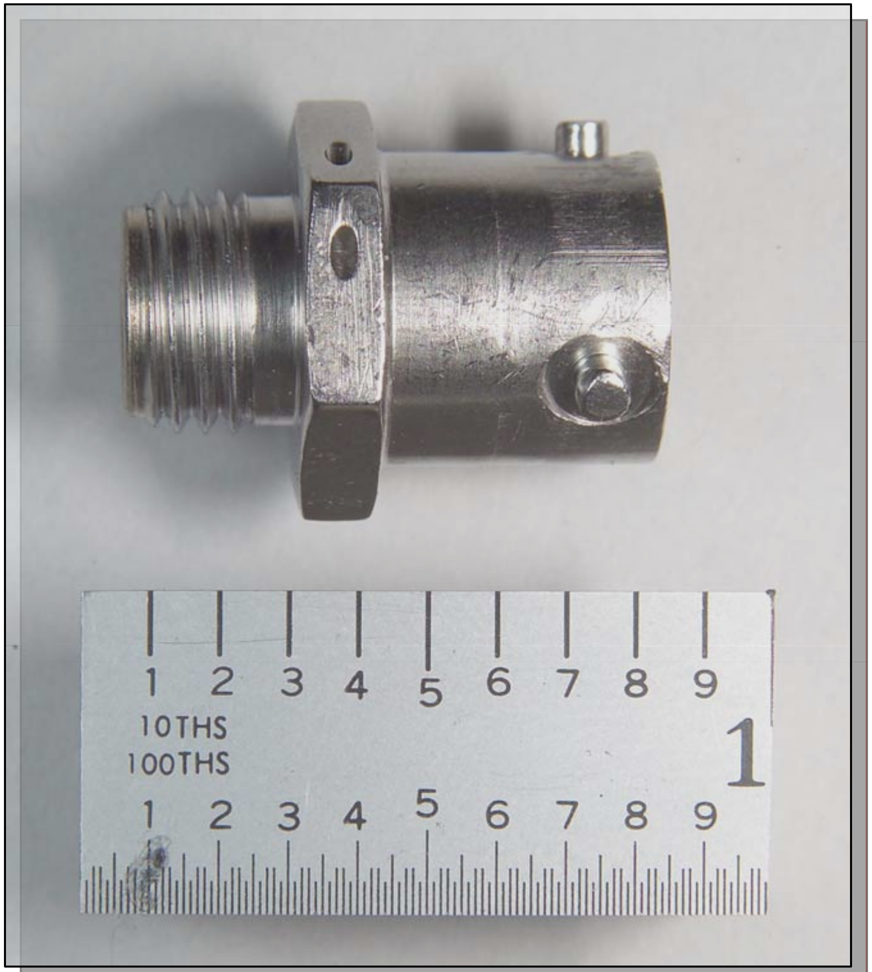
[2] A test chamber leak was noticed during Test 1 with the packed THPP

# Approach

- An initiator body, similar to those used in many pyrotechnic aerospace applications, was loaded with a standard booster charge consisting of a mixture of titanium hydride and potassium perchlorate (THPP).
- Embedded in the powder was a 0.002-in. diameter 304L stainless steel wire. In this configuration, the wire is commonly called a bridgewire.
- A programmable power supply was used to vary the heat applied to the THPP by changing the amperage of the current applied to the bridgewire.

# Approach (continued)

Test Article



# Approach (continued)

- Amperage was held constant during each pulse.
- As the bridgewire heats, its electrical resistance increases. The power supply maintains the constant current at the higher resistance by increasing the voltage.
- The autoignition temperature is calculated from the initial resistance and temperature at ambient conditions, and the coefficient of thermal resistivity of the bridgewire.

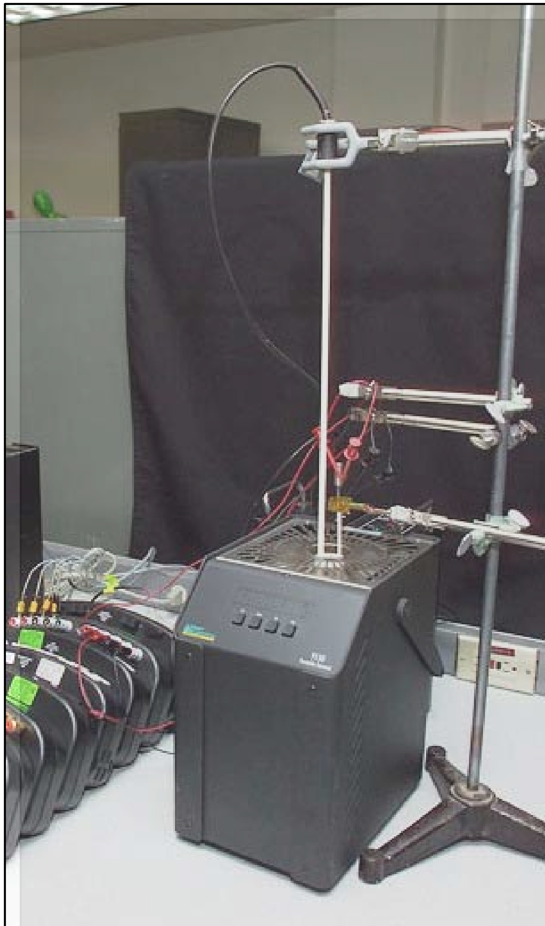
# Approach (continued)

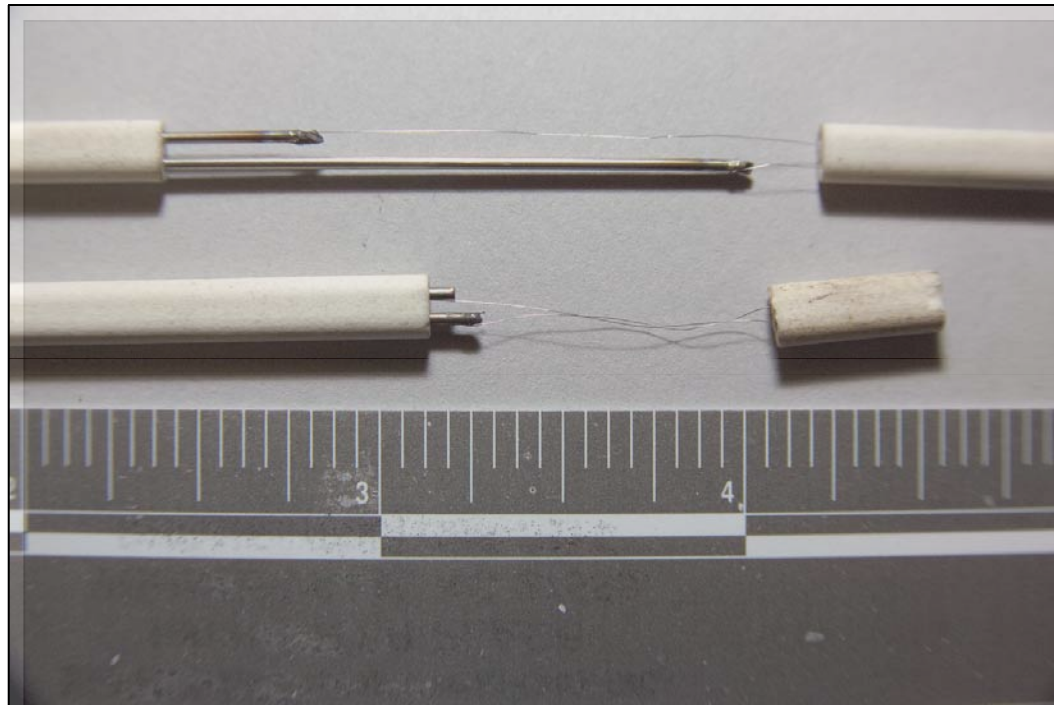
- Because the coefficient of thermal resistivity of the bridgewire material is a key parameter in the temperature calculation, it was checked in a separate test.

# Coefficient of Thermal Resistivity

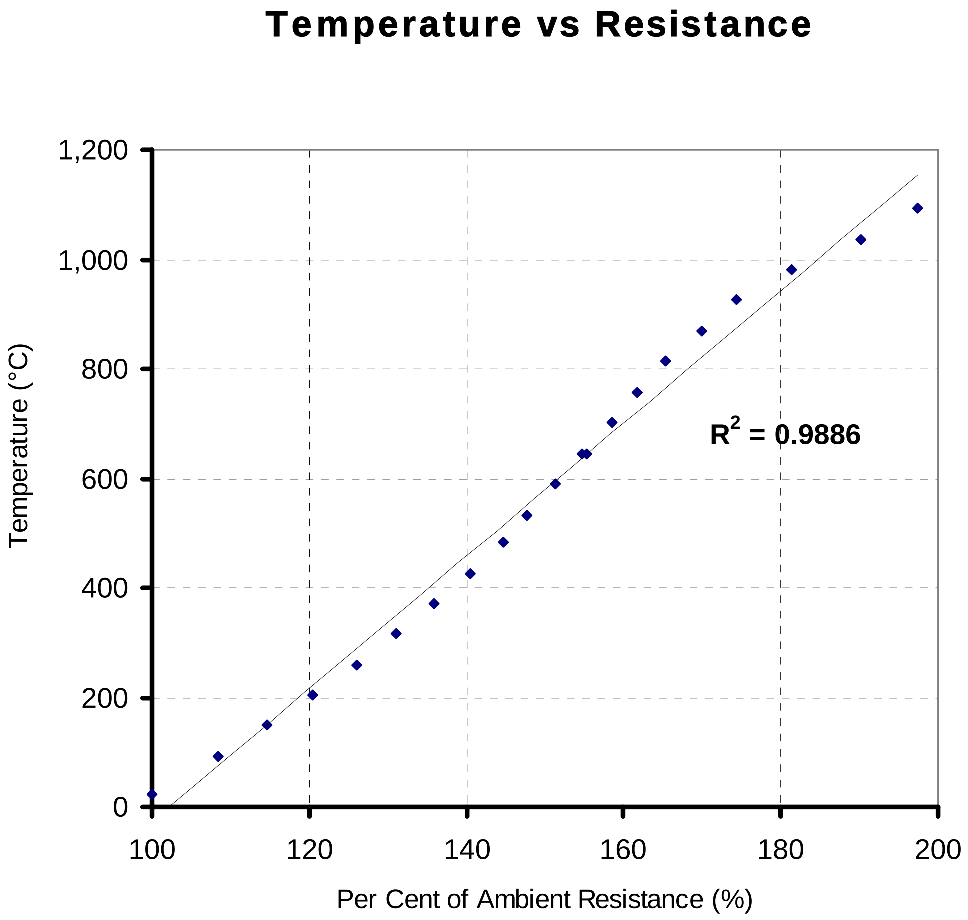
- A sample of the bridgewire was obtained from the manufacturer.
- The sample was heated in a calibrated furnace to temperatures ranging from 23.6 °C (74.48 °F) to 1050.98 °C (1923.77 °F). When the temperature had stabilized, the bridgewire resistance was measured to four decimal places.
- The coefficient was determined to be 865 ohms per million ohms per °C.

# Coefficient of Thermal Resistivity (continued)





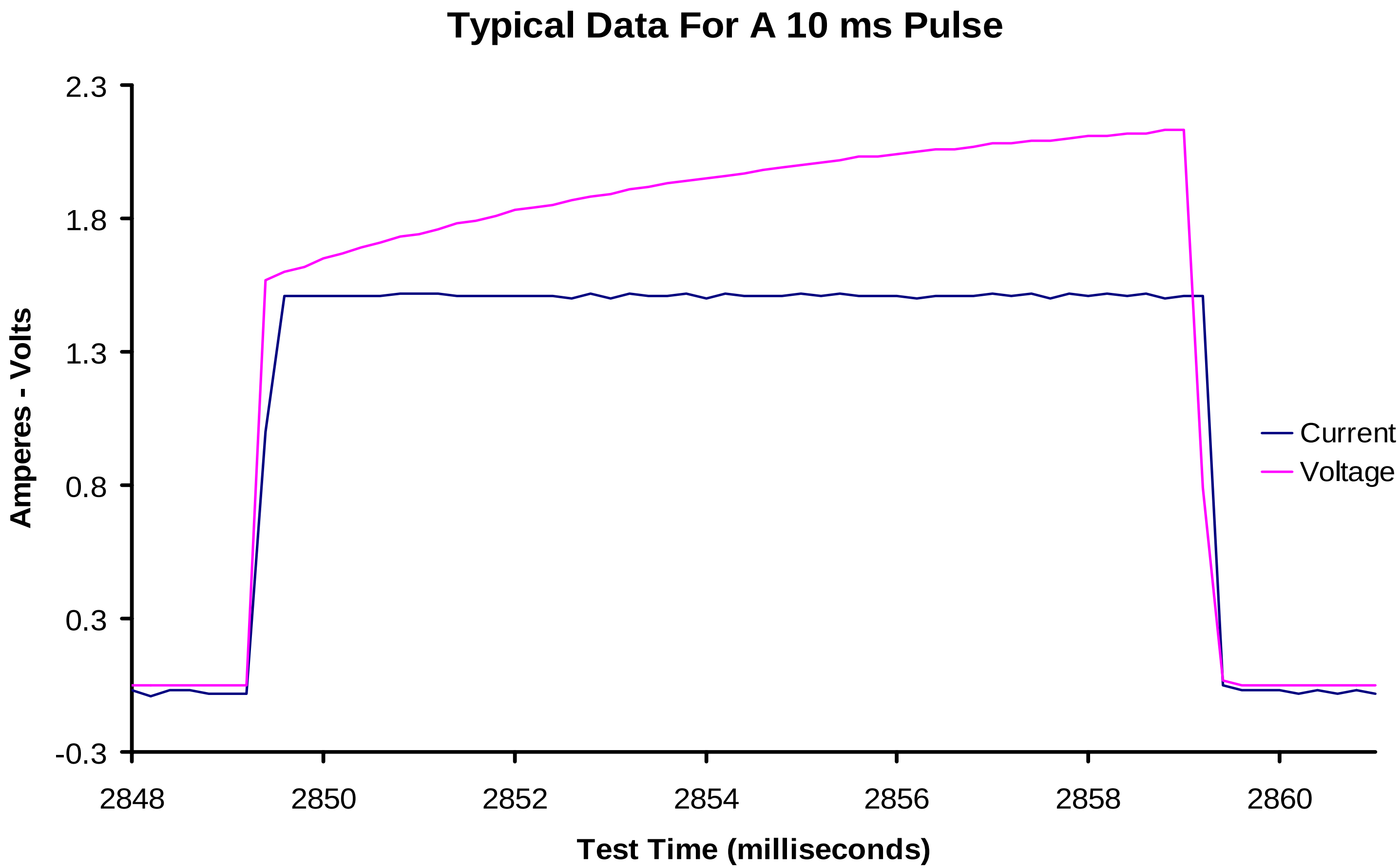
# Coefficient of Thermal Resistivity (continued)



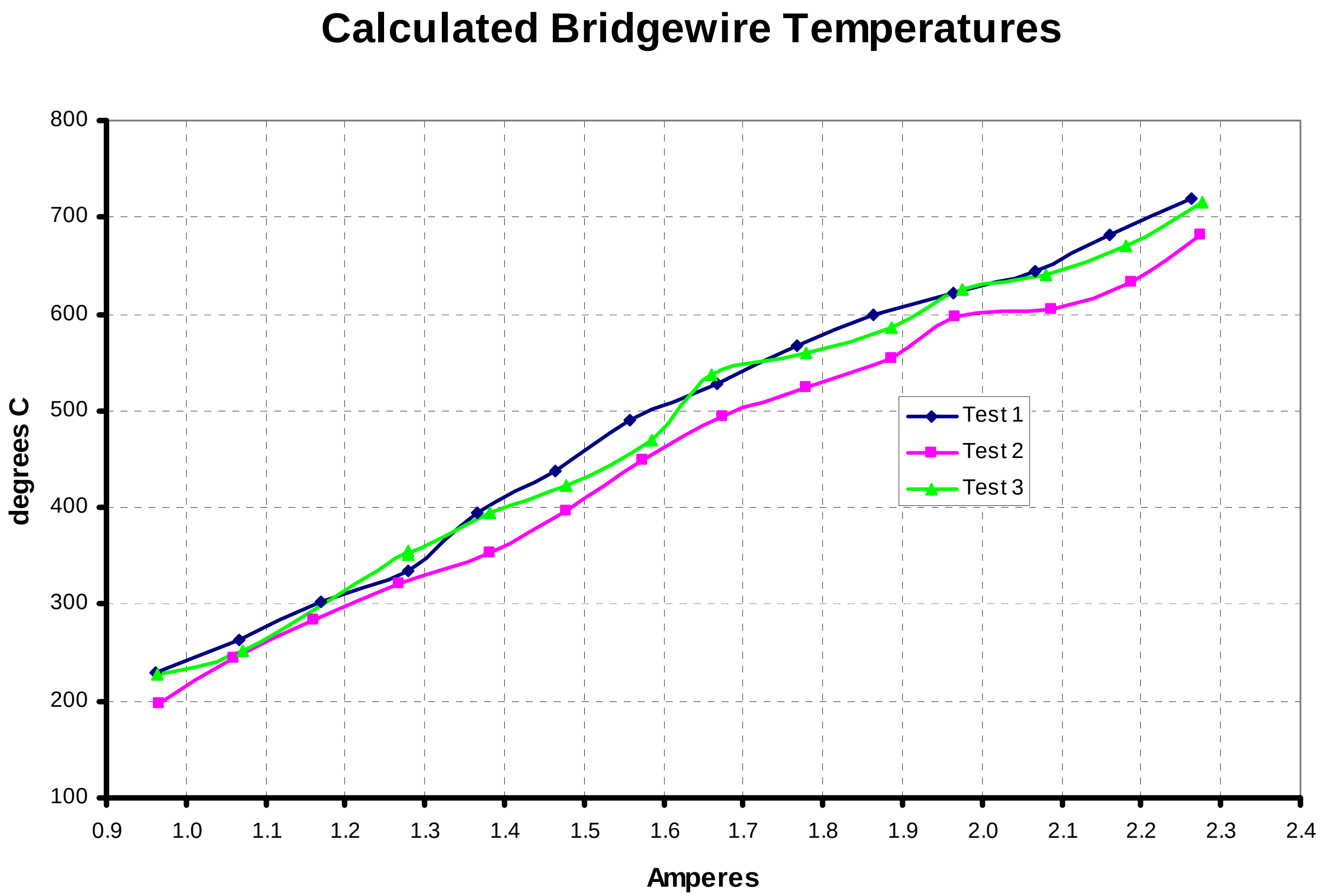

# 10 ms Pulse Tests

- The first pulse was set at 1.0 amperes.  After a 3-min wait to allow the bridgewire to cool, the amperage was increased by 0.10 amperes and another 10-ms pulse was applied.
- The amperage was raised in 0.10 ampere steps until autoignition was achieved.

# 10 ms Pulse – Typical Data




# Bridgewire Temperatures at End of 10-ms Pulses

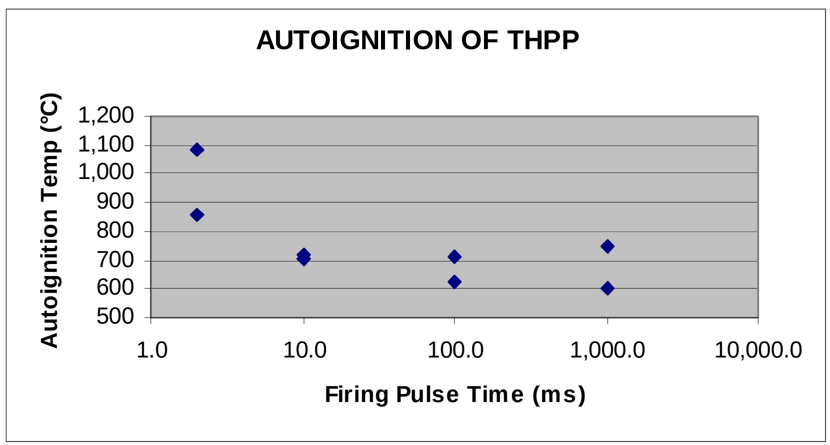


# Autoignition Tests Performed

- The last recorded current and voltage just before the autoignition were used to calculate the ignition temperature.
- Pulse width was changed for subsequent tests; two units were tested with a 1,000-ms pulse, two units with a 100-ms pulse, and two units with a 2-ms pulse.

# Autoignition Temperature Results

| Summary of Bridgewire Autoignition Tests of THPP | | | | | |
|---|---|---|---|---|---|
| Test | Programmed Time of Firing Pulse (ms) | Actual Time of Firing Pulse (ms) | Amperage of Firing Pulse (amps) | Maximum Temperature Reached (°C) | Fired During or After Pulse |
| 1 | 2.0 | 1.76 | 4.97 | 1,082 | After Pulse |
| 2 | 2.0 | 1.76 | 4.47 | 860 | After Pulse |
| 3 | 10.0 | 9.60 | 2.26 | 701 | After Pulse |
| 4 | 10.0 | 9.60 | 2.28 | 705 | After Pulse |
| 5 | 10.0 | 9.60 | 2.27 | 719 | After Pulse |
| 6 | 100.0 | 49.40 | 1.47 | 627 | During Pulse |
| 7 | 100.0 | 70.40 | 1.53 | 714 | During Pulse |
| 8 | 1,000.0 | 178.00 | 1.46 | 603 | During Pulse |
| 9 | 1,000.0 | 311.00 | 1.52 | 746 | During Pulse |



# Conclusion

- Autoignition temperatures determined by the bridgewire resistance method are far higher than those determined by the standard methods.
- The bridgewire resistance method more closely simulates what the ordnance materials will experience in service.
- The valuable information gained by using this method could help in determining margins for actuation and in more accurate modeling of ordnance initiation mechanisms.